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THE EARTH'S MAGNETIC FIELD

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Magnetic Surveys

Ground Surveys of a General Character.

Systematic magnetic surveys on the ground began in different countries in the second half of the 19th century. Countries which had well developed communications were covered with a dense network of points of absolute magnetic determinations. Observations for inclinations, tipplings and horizontal components were carried out. The distance between points varied in the countries (from 10 to 60 km). Observations in almost inaccessible regions, where dense ("continuous") surveys were impossible, were carried out according to individual routes of diverse density at distances between the points on the routes of 40 + 60 km.

Continuous magnetic surveys were carried out: in France in 1884-1895 at points 20 km apart, in England in 1889-1892 every 30-40 km, in Japan in 1893-1896 every 45 km, in Germany in 1898-1903 every 40 km, in India in 1901-1920 every 30-40 km, in the U. S. in 1899-1937 every 40 km, and in other countries as well. Later on many surveys were repeated.

Surveys in undeveloped and dependent countries were carried out by expeditions of other countries, mainly by the U. S. A. Thus, the following magnetic surveys were accomplished by the Carnegie Institute: in China in 1906-1936 at points 50-60 km apart, in Australia in 1906-1944 according to a scattered (mainly route) network, and in Africa in 1905-1934 in accordance with the scattered routes.

Magnetic observations in pre-revolutionary Russia were carried out by individual scientists, together with different expeditions, without any support of the Tsarist government. Thus, for instance, in 1871-1878 I. N. Smirnov (an associate professor of Kazan University) accomplished the first systematic scattered reconnaissance survey of Russia. A number of anomalous regions, namely, in Kursk Guberniya, near the Urals and Riga etc, were discovered by this survey. Smirnov's thorough and accurate observations made it possible, in the future, to use his points for the determination of secular variations of magnetic elements, and also to define more accurately available magnetic maps.

Taking into consideration the necessity of a continuous magnetic survey of Russia, the Academy of Sciences, already in 1893, developed a project of surveys, but a shortage of funds delayed these measures.

Extensive undertakings in the field of study of the earth's magnetism, conducted abroad at the end of the 19th century and at the

beginning of 20th century, continued to stir Russian scientists. In the 20th century the Academy of Sciences raised again the question concerning the magnetic survey. M. A. Rykachev, who was the director of the Main Physical Observatory, in 1909 at the 12th conference of Russian naturalists and physicians said: "the necessity of magnetic surveys in Russia is great, and if we will disregard these measures, then this problem will be solved by Americans." However, these surveys (at 664 points of continuous and at 514 points of route surveys) were accomplished during the period from 1910 to 1917, due to efforts of the Russian Academy of Sciences, certain institutions and even private persons. Peterburgskaya, Novgorodskaya, Pskovskaya and Podol'skaya Guberniyas were partly covered by a continuous magnetic survey. Certain rivers in Siberia and partly the north of European Russia were covered by a route survey.

In 1917 only about 4500 points of magnetic determinations were found in the entire territory of Russia.

The systematic study of terrestrial magnetic phenomena in Russia has begun only after the Great October Socialistic Revolution. On August 21 of 1930 the Soviet People's Commissars of the USSR decreed to carry out the general magnetic survey of the USSR.

The survey was undertaken in 1931. All accessible regions of the country, which had a developed network of communications, were covered by the continuous magnetic survey. The average distance between these points was 20 km. The survey in almost inaccessible and sparsely populated regions was carried out along rivers, roads, paths and sea coasts. The average distance between these points for route observations was also 20 km.

Relative determinations of the ΔZ vertical component were introduced every 2 km along the route of survey units, first in the most important regions and since 1935 in all groups of the general magnetic survey (GMS).

The general magnetic survey of the USSR was a great undertaking, and all magnetologists of the country participated in these operations. Besides the bureau of the GMS of the Main Geophysical Observatory, the following establishments participated in this great work: The Moscow, Tashkent, Odessa, Sverdlovsk, Irkutsk, Kazan', Tifliss and Vladivostok magnetic observatories, the departments of physics or geophysics of Tomsk, Kiev, Khar'kov, Smolensk and Rostov-Don universities, the Main Hydrographic Administration, the Main Administration of the North Sea Route etc.

During the period from 1931 to 1952 altogether 531 expeditions were engaged in these operations, and the D, H, and J magnetic determinations were carried out at 27,000 points. Relative

determinations of the vertical components were performed at more than 100,000 points. With respect to tempos of operations, methods of observations and the control density of determinations of the ΔZ vertical component, the general magnetic surveys were found better than comparative surveys in foreign countries. As a result of these operations, the general and complicated character of the magnetic field of the USSR was revealed.

Besides the general magnetic survey on the ground, a marine magnetic survey was carried out both in the Soviet Union and abroad and, during recent decades, ground detailed and aeromagnetic surveys were also accomplished.

Marine Magnetic Surveys

The first marine observations of magnetic fields were performed more than 200 years ago (in 1698-1700) by Halley (an English astronomer) on the sailing vessel "Paramour Pink". Before the 20th century the total number of magnetic determinations on oceans was insignifacant. Inclinations were mostly observed chiefly along coasts of continents and islands. These observations were performed on boats of different countries.

The systematic survey of oceans was initiated in 1905 by the Carnegie Institute of the U. S. During the 1905-1908 period about 450 points were surveyed by the boat "Galileo" in the Pacific Ocean, where upon the average distance between these points was 200 sea miles. Since 1909 the survey was carried out by the special yacht "Carnegie", which was constructed in the U. S. During the 1909-1929 period the Pacific, Atlantic and Indian Oceans were covered by a network of routes, which were 500 + 1000 sea miles from each other. The distance between the points was on the order of 100 + 150 sea miles. The most systematic network of routes was accomplished in the Pacific Ocean, and the most scattered one in the Indian Ocean. Altogether during 1905-1929 about 6000 points were surveyed on oceans by the U. S. This small number of determinations in the vast water areas made it possible to obtain only very limited data concerning magnetic fields in these oceans. In 1929 the boat "Carnegie" sank and sea magnetic surveys were discontinued for 25 years. Only in 1955 were these magnetic surveys resumed by the Soviet non-magnetic sailing-motor vessel "Zarya."

Picture on page 10: The non-magnetic sailing-motor vessel "Zarya."

The vessel "Zarya" is equipped with the newest instruments, which make it possible to perform continuous measurements of non-magnetic elements while this vessel is moving. Due to these improvements the "Zarya" differs advantageously from the vessel "Carnegie."

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In 1955-1956 the "Zarya" carried out certain magnetic surveys in the Baffin, North, Greenland, Barents and White Seas, and defined more accurately the magnetic field within the limits of these seas. At present the "Zarya" is the only non-magnetic vessel which, while participating in the work of the International Geophysical Year (IGY), also performs sea magnetic surveys.

In accordance with the program of the International Geophysical Year (IGY) the "Zarya" during the period from August of 1957 to the end of 1958 carried out a number of expeditions in the Atlantic and Indian Oceans. The "Zarya" left Leningrad in August of 1957 and completed the following passages: Leningrad-London-Halifax-the Azores-Cadiz-Durres-Gibraltar-Puerto Rico-Belen (Brazil)-Freetown-Takoradi-Buenos Aires-Cape Town-Perth (Australia)-Jakarta-Island Mavrilia-Colombo (Ceylon)-Port Said-Istanbul-Odessa. Continuous measurements of geomagnetic elements were carried out along the entire route, which gave new data concerning the magnetic field in these oceans. In addition, the "Zarya's" observations, in places where it crossed the passages of the "Carnegie", make it possible to determine the amount of secular variations of magnetic elements in these water areas during the last 30 + 40 years. These data are very important for a more exact definition of world magnetic maps.

Systematic magnetic surveys of the Arctic and Antarctic Oceans did not exist before the beginning of the 20th century. A small number of determinations of magnetic elements, mainly of declination were found only at individual points.

The magnetic field of the entire Arctic has not yet been sufficiently studied. The Soviet area is much better investigated due to operations of the drifting stations "North Pole-1" and "North Pole-7".

The magnetic field of the Antarctic also has not yet been sufficiently studied. There were observations (mainly declinations) approximately at 800 points at sea and along sea coasts in this vast area, which is located to the south of 60° South Lat. prior to the beginning of operations of the Antarctic expedition. The first magnetic observations in the Antarctic were performed by I. M. Simonov (a professor of Kazan University), who was a participant of Bellingshausen and Lazarev's expedition, which was undertaken on the sloops "Vostok" and "Mirny". These vessels left the port of Kronstadt in 1819.

A detailed investigation of the Antarctic is a part of the program of the International Geophysical Year. At present, several geophysical stations of different countries operate in the Antarctic, where together with magnetic observations a great complex of geophysical

investigations is carried out.

The observatory "Mirnyy" and the stations: "Pionerskaya," "Komsomol'skaya," "Sovetskaya", "Oazis", and "Vostok" have been established by the Soviet Union. The station "Vostok" is located near the southern geomagnetic pole, approximately 1500 km from the "Mirnyy" at an elevation of 3400 m above sea level.

Detailed Ground Surveys

At the beginning of the 20th century a close interconnection between the earth's magnetic field and its geological structure was established. This interconnection is explainable by the fact that separate rocks, which are included in the composition of the upper crustal layers of different magnetic properties, cause various distortions of the geomagnetic field. For instance, the smooth motion of lines of force of the magnetic field above iron ore deposits is disturbed, and local distortions of the magnetic field, i. e., magnetic anomalies appear. Consequently, a detailed magnetic survey is carried out in places where the presence of iron deposits is suspected. This survey must have a dense network of points, according to which a map of the Z anomalous values is compiled. If necessary, such a survey, in the most anomalous sections, can be more condensed, and sometimes the distance between observation points can be brought to several meters.

Thus, using the magnetic method of geophysical prospecting, which is the cheapest in comparison with other geophysical methods, we find out the extent of anomalous sections, and then establish shafts, boreholes etc. According to data of a detailed survey of the given section, which includes anomalous variations, it is possible to calculate the depth of ore beddings, which caused this anomaly, and also to determine their forms.

The Kursk magnetic anomalies, which have been considered the largest in the entire world, were discovered in the seventies by I. N. Smirnov only by means of magnetic surveys. A thorough study of these anomalies was initiated at once at the beginning of the Soviet period. As a result of detailed magnetic surveys, which were carried out in the Kursk oblast' in 1919-1923, large deposits of iron ore were discovered.

A vertical magnetic field balance was invented in the twenties of the current century, which made it possible to perform relative measurements of the ΔZ vertical component with great rapidity (3 minutes of observation per point) and also with high accuracy, on the order of 20-30 gammas. Due to these qualities the vertical

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magnetic field balance has been used for detailed surveys connected with the search for minerals. During relative surveys the absolute value of the Z vertical component is not measured, but only its increase $+\Delta Z$ or decrease $-\Delta Z$ with respect to the initial point of relative surveys. If the absolute value of Z is known at the initial point, then it is easy to transfer the ΔZ values at all the points of a relative survey into absolute values. As larger and larger areas were covered by surveys, new features of a geomagnetic field were developed, and the importance of geomagnetic field for geology increased.

At present the magnetic method of prospecting is used not only for the search of minerals, but also for the solution of certain problems connected with structural geology. In the last case, magnetic surveys sometimes envelop large areas. Aeromagnetic surveys for geophysical prospecting were initiated in the thirties of the present century.

Aeromagnetic Surveys

A. A. Lugachev, who is a Russian geophysicist, is the creator of the aeromagnetic survey. Beginning from 1936, for the first time in the world, a relative aeromagnetic survey of the ΔZ vertical component was carried out by Lugachev. This survey was performed by means of Lugachev's device, the so-called induction Z aeromagnetometer, in order to discover deposits of mineral resources. Later on, such aeromagnetic surveys have also been extensively used abroad.

Vast areas were covered by the ΔZ survey (at scales of 1:1,000,000, 1:200,000 and larger), and it is especially important that distant regions were surveyed, which before due to the lack of roads were almost inaccessible. Aeromagnetic surveys, if relief was level, were carried out at a low altitude, on the order of 200-300 meters. Anomalies discovered by these surveys later on were defined more accurately by the ΔZ relative ground magnetic surveys. As a result of aeromagnetic operations, many important ore deposits were discovered.

An insufficient accuracy of aeromagnetic surveys (on the order of ± 200 gammas) made it impossible to use them for detecting small distortions of the magnetic field connected with the structure of upper layers of the earth's crust. Consequently, the research for a more perfect construction of aeromagnetometers was extended.

During the last decade, a high-precision T-aeromagnetometer was finally devised for relative measurements of the full force of the T geomagnetic field. This instrument provides a magnetic survey during motion with an accuracy on the order of several tens of gammas.

Vast areas in the Soviet Union and also abroad are covered by the AT aeromagnetic surveys. In the near future the entire territory of the Soviet Union will be covered by such surveys at a scale of 1:200,000 and larger. At the same time, ground surveys also will be carried out for a more exact definition and details of separate areas of aeromagnetic surveys.

Magnetic Observatories

Continuous and high-precision measurements of elements of the earth's magnetism are carried out at magnetic observatories. In order to avoid industrial disturbances (electric current creates an additional magnetic field), observatories are usually built far from towns, electrified railroads, trolley lines etc.

Pavilions, where instruments are installed, must not contain magnetic materials. All metallic parts of these pavilions (pipes of heating, nails, loops, doorhandles etc) are made from non-magnetic materials (brass, bronze, copper).

At present, more than 100 operating magnetic observatories are found in the entire world, and more than 20 of them are located in the Soviet Union. The list of the magnetic observatories located in the Soviet Union is shown in table 1.

Table 1.

Name of Observatories	Latitude	Longitude
	(+ NL - SL φ	λ
Tikhaya Bay	+80° 20'	52° 48'
Cape Chelyuskin	+77° 43'	104° 17'
Dickson	+73° 30'	80° 24'
Tiksi Bay	+71° 40'	128° 54'
Murmansk	+68° 57'	33° 03'
Uellen	+66° 10'	190° 10'
Srednikan	+62° 26'	158° 19'
Yakutsk	+62° 01'	129° 40'
Leningrad (Voznykovo)	+59° 57'	30° 42'
Sverdlovsk (Vysokaya Dubrava)	+56° 44'	61° 04'
Kazan' (Zaymishche)	+55° 50'	48° 51'
Moscow (Krasnaya Pakhra)	+55° 29'	37° 12'
Irkutsk (Zuy)	+52° 28'	104° 02'
Kiev	+50° 43'	30° 18'
L'vov	+49° 54'	23° 45'
Yuzhno-Sakhalinsk	+46° 57'	142° 43'
Odessa (Stepanovka)	+46° 47'	30° 54'
Vladivostok (Gornotayezhnaya)	+43° 39'	132° 31'

Tbilisi (Dudubi)	+42° 05'	44° 12'
Tashkent (Koles)	+41° 25'	69° 18'
Ashkhabad	+37° 56'	58° 22'
Kerry	-66° 33'	93° 01'
Pionerskaya	-69° 44'	95° 10'
Vostok	-78° 27'	106° 52'

The observatory, which is located at Tikhaya Bay (on Franz Josef Land), is the most northern of all the magnetic observations of the USSR, operating at present. The observatory "Vostok" is the most southern station, which was opened at the end of 1957 (for the period of the International Geophysical Year) in the area of the southern geomagnetic pole.

It is very likely that some of the opened temporary magnetic and geophysical stations (during the period of the International Geophysical Year) will be maintained as permanent operating observatories.

Instruments for the D, H and Z absolute measurements and also for the recording of time variations of the magnetic fields are found at these observatories. They are called magnetographs and consist of the D-H and Z variometers and the recording part.

The working principles of the magnetograph are very simple. Magnets of the D and H variometers are suspended on vertical threads and can revolve in the horizontal plane, the magnet of the Z variometer, having the horizontal axis of support, revolves in the vertical plane. A thin shaft of light from a small electric bulb, reflecting from a mirror which is securely fastened with the variometer magnet, falls on the phototape put on the drum, which is uniformly rotated by means of a clockwork (usually at a speed of one turn within 24 hours). A continuous line, i.e., a curve of a different degree of bend, depending on the position of the magnet, appears on the tape after the development. The second pencil of light reflected from the fixed mirror traces a straight line on the tape, which is called the base line.

The tape of the magnetograph (magnetogram) is shown in Fig. 3. The distance in millimeters from some point of the curve on the tape to the base line for any moment of time, for instance for 9h 15min, multiplied by the sensitivity of the variometer (a scale of a millimeter interval expressed in gammas or minutes), yields an amount of deflection (an ordinate) of a magnetic element from the base line in the given time. During the processing of tapes in observatories, an average amount of the ordinate of curve is found for each time interval with the duration 60 minutes from the whole hour to the next, and according to this amount the average value of the corresponding magnetic element for this interval of time is determined. Each observatory, according to its tapes, prepares monthly tables of such "average hour" values of magnetic elements for every hour, day and month.

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November 4, 1957 a

November 5, 1957 b

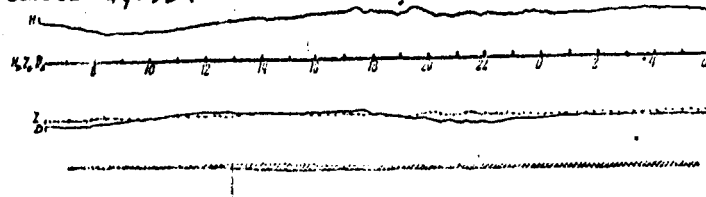


Fig. 3. A magnetograph tape of the observatory located in Voeykovo with recordings of the D, H and Z variometers, "basis" line (D_0 , H_0 , Z_0), and hour marks.

Absolute observations make it possible to obtain values of magnetic elements, which correspond to base lines, and consequently to express data of magnetographs, for any moment of time in absolute amounts.

During magnetic surveys in areas far from magnetic observatories, field variation stations are used, which are lighter and more compact than instruments of observatories.

Results of observations of magnetic observatories for each month are shown in tables of hourly values of magnetic elements, where mean, minimum and maximum values of magnetic elements (for a month) are indicated. Average annual values are obtained from average monthly data.

These tables are also used for the introduction of corrections for variations in values obtained during magnetic surveys. When values of magnetic elements are sharply changed, then corrections for variations are determined directly from magnetograph tapes.

Graphic Representation of the Earth's Magnetic Field

A very convenient and graphic method of isolines, i.e., lines traced through the points with the same values of magnetic elements, is usually used for the representation of a magnetic field on maps. Isolines of separate elements have a special name. Isolines of inclination are called isogons, isolines of tipping--isoclines, and isolines of separate components and of the total force are called isodynamic lines.

In view of a continuous change of magnetic elements, later on corrections of variations are introduced into their values.

Observations carried out at different points during various hours, days and years are brought to a single moment of time, usually

to the middle of the year, for instance to July 1 of 1950. Later on, these reduced values of magnetic elements are plotted on maps.

Magnetic maps differ depending on the area, scale and degree of representation of the magnetic field, which they envelop. Thus, large-scale maps are constructed for small areas of detailed surveys with a dense network of points, which describe all characteristics of the field. Small scale maps with smoothed isolines are constructed in those cases when details are unnecessary for large territories, and only basic features are required. Magnetic maps of the entire earth, the so-called world magnetic maps, belong to small-scale categories. The world magnetic maps of inclination, horizontal and vertical components, of the 1950 epoch are shown in fig. 6, 7 and 8. These maps are constructed by the Scientific Research Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation.

It is obvious, even with a brief survey of these diagrams, that the isodynamic lines of the horizontal and vertical component have a direction close to geographic parallels, and the isogonic lines are mainly directed along meridians. All the isogonic lines come together at four points of two magnetic and two geographic poles. The geographic poles are outside these diagrams. The magnetic pole found in the northern hemisphere is called the north magnetic pole. The magnetic pole found in the southern hemisphere is called the south magnetic pole.

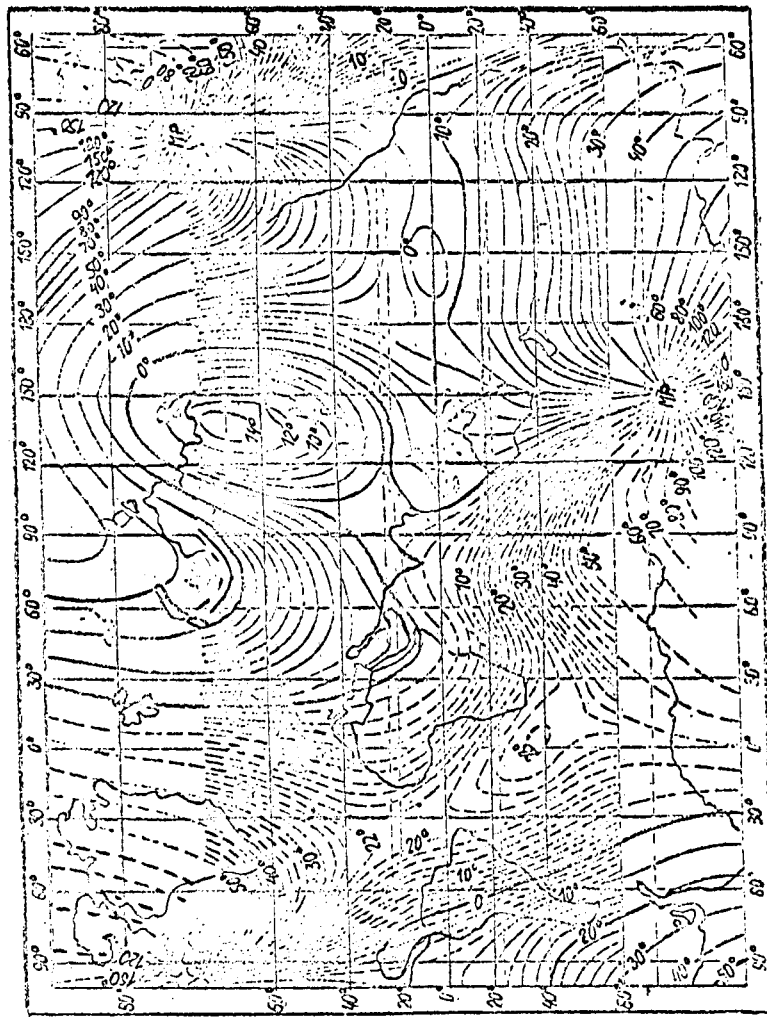


Fig. 6. World map of the magnetic declination of the 1950 epoch. — is the eastern declination, and --- is the western declination.

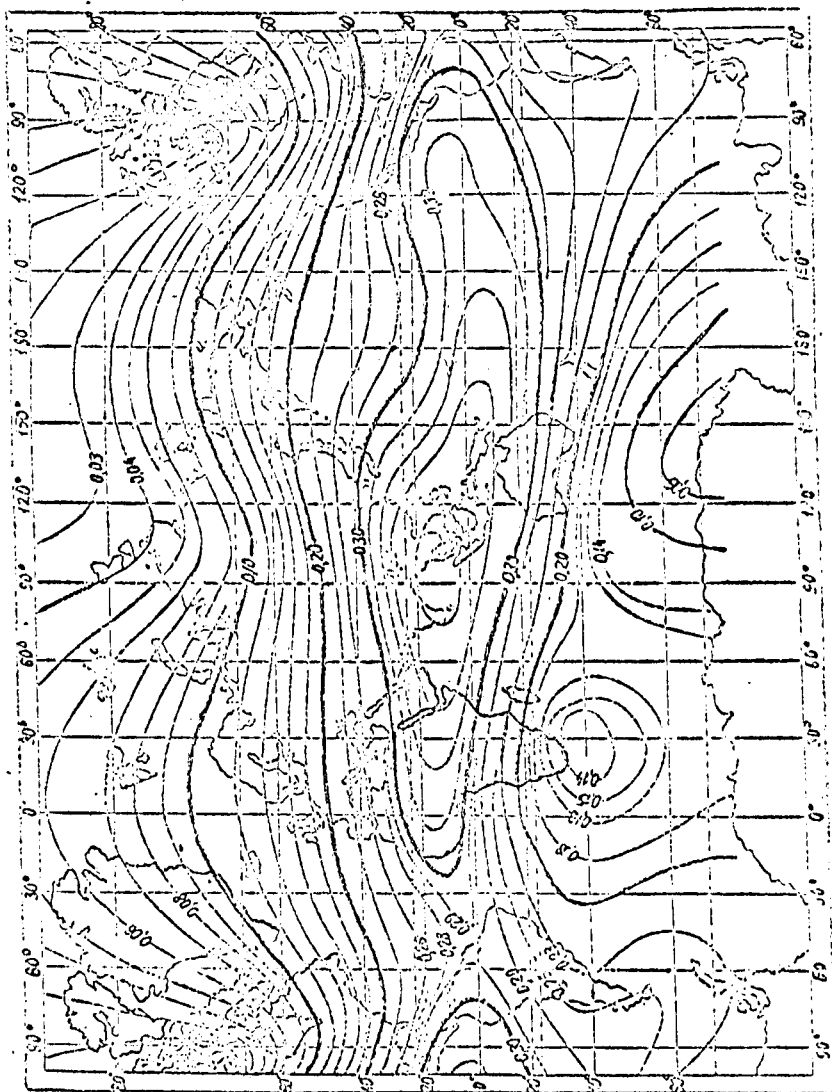


Fig. 7. World map of the horizontal component of the 1950 epoch.

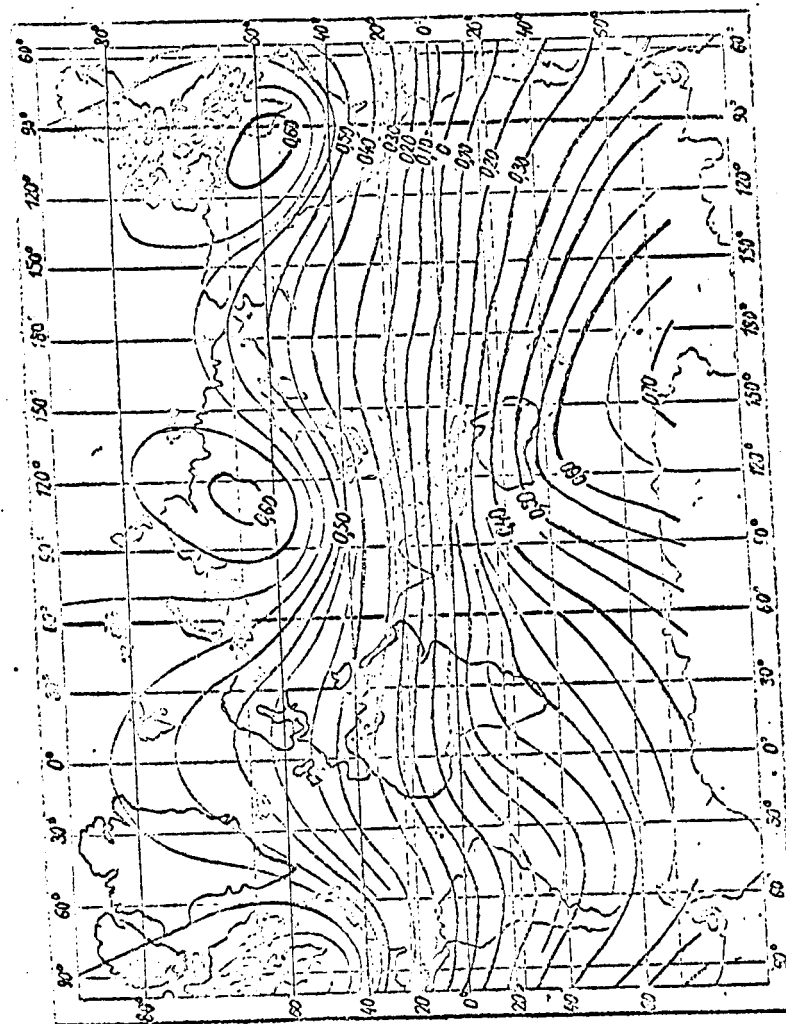


Fig. 8. World map of the vertical component of the 1950 epoch.

Approximate coordinates of the magnetic poles shown on the world magnetic map of the 1955 epoch are:

North Pole

$\varphi = 74^\circ$ N. Latitude

$\lambda = 260^\circ$ E. Longitude

South Pole

$\varphi = 69^\circ$ S. Latitude

$\lambda = 145^\circ$ E. Longitude

The $J = 0^\circ$ inclination and the $H = 0$ horizontal component are at the magnetic poles, therefore, the magnetic needle which revolves freely around the horizontal axis (the dip needle), will settle vertically at the magnetic poles, with the northern end downwards at the North Pole, and with the southern end down at the South Pole. We know that the compass needle which revolves in horizontal plane, assumes certain position owing to the directive influence of the horizontal component only. Consequently, the compass becomes useless at the magnetic poles where the horizontal component H equals zero, because the compass needle there will preserve any imparted position.

In addition to the magnetic poles, isogonic lines also converge at the geographic poles. This follows from the very definition of declination as an angle between the magnetic and geographic meridians. Since all the geographic meridians converge at the geographic pole, the declination there will assume all the values from 0° to 360° , i.e., it will become indefinite, even if the compass needle adopts at the geographic pole a single and quite definite bearing. Consequently, the compass cannot be used at the magnetic poles, if we have only the map of magnetic declination. Therefore the modified maps of declination, i.e., the maps of directional angles are used for the flights in the circumpolar regions.

The distribution of the isoclinal lines on the surface of the terrestrial globe is close to the distribution of the isodynamic lines Z . The inclination decreases gradually from 90° at the poles, to zero around the equator. The zero isoclinal line, rounding the terrestrial globe, passes near the geographic equator. It is called the magnetic equator. The vertical component, which has the maximum value near the magnetic poles (0.60 and 0.70 oersted), decreases to zero at the magnetic equator. The horizontal component, on the contrary, has its maximum value at the magnetic equator; it is equal here to 0.4 oersted, and gradually decreases towards the poles.

Structure of the Earth's Magnetic Field. Magnetic Anomalies

In the first, rather rough approximation, the earth's magnetic field can be presented as a field of a globe with a uniform magnetization; the direction of its magnetization forms an angle of about 12° with the earth's axis of rotation. The scheme of such field is given in Figure 9.

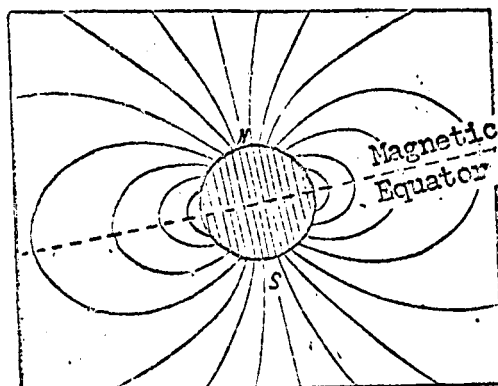


Figure 9. The Field of the Uniformly Magnetized Globe

The points on the earth's surface, where this surface is intersected by the axis of symmetry of a main part of the earth's magnetic field and the earth's uniform magnetization, are called geomagnetic poles. According to computations, these poles are: at the point $70^{\circ}30'$ N. Lat., 291° E. Long. in the northern hemisphere; and at the point $70^{\circ}30'$ S. Lat., 111° E. Long. in the southern hemisphere. The conventional positive direction of the magnetic field's force lines is a direction in which will shift the positive magnetic mass, introduced in this field (It is taken for granted that the positive magnetic masses are concentrated in the northern end of a magnet). It is therefore believed that the force lines of the earth's magnetic field come out on the earth's surface in the southern hemisphere, and go into the interior of the earth in its northern hemisphere. In the case of uniform magnetization, the magnetic elements must change smoothly from point to point. In reality, this is not observed with the actually-existing terrestrial field. Even on the smoothed out world charts, the monotonous change of the value of magnetic elements is badly disturbed. For example, a large region (Figure 8) exists in the northeastern part of the Soviet Union, where the vertical component reaches the value $Z=0.60$ oersted, i.e., such, as exists in the region of the northern magnetic pole, and the magnetic declination becomes western and not eastern (fig. 6), as it were in the case of homogeneous magnetization only.

On the charts of actual distribution of the vertical component with unsmoothed isolines, one can see numerous disturbances in a smooth variation of Z in the areas, relatively small by size. These disturbances are caused by heterogeneous magnetization of rocks in the earth's crust, by their variable thickness and tectonic disturbances.

The distortions of the magnetic field are called the magnetic anomalies, which are subdivided into local, regional, and the world magnetic anomalies.

The local anomalies are local disturbances of the field, and can be observed over areas of several kilometers. Such anomalies arise owing to the influence of rocks of limited extent, embedded near the earth's surface.

The regional anomalies cover areas which spread for tens and hundreds of square kilometers and are caused mainly by the structural, petrographic, or tectonic formations.

The world anomalies, involving territories of whole continents, do not have a generally accepted explanation for their existence. Some magnetologists believe that these anomalies are associated with the processes, taking place in the earth's core; the others assume that these anomalies arise from the magnetic rocks in the earth's crust and in the subcrustal layer of large blocks or platforms.

According to the contemporary geological ideas, the earth's crust consists of separate, relatively stable segments or platforms, separated by less stable and more mobile sectors, or geosynclines. The platforms, formed by the ancient crystalline rocks, contain depressions and protrusions. For example, the protrusions of the Russian Platform, appearing on the surface in Sweden, Finland, Karelia, as well as on the Kola Peninsula, are the sources of numerous local anomalies, well-known in these regions. On the sites of depressions in the platforms where thick deposits of slightly magnetic sedimentary rocks are accumulated as, for example, in the lowland of the Caspian Region, the magnetic field is notable by a very stable character.

The stable magnetic field of the earth can be regarded as a sum of fields of uniform magnetization, and a field of the world, regional and local anomalies. Let us denote the intensity of the field of uniform magnetization by T_0 , and the intensities of the world, regional, and local fields, respectively, by T_w , T_r , and T_l . Then, the intensity of the observable field T can be represented by the expression

$$T = T_0 + T_w + T_r + T_l.$$

The sum of the fields of uniform magnetization and of the world anomalies, $T_0 + T_w$, are called the "normal" magnetic field. The normal field is used to single out the regional and local magnetic anomalies.

We denote the normal field by T_n , and represent it in the following way:

$$T_n = T - T_r - T_l.$$

Consequently, to obtain the normal field, the fields of regional and local anomalies must be subtracted from the observable field.

In practice, diverse methods are employed in the compilation of the charts for a normal field of magnetic elements. They are equally good with respect to the resulting accuracy. With respect to the external appearance, the charts of normal field resemble the world magnetic charts.

Hypotheses Concerning the Origin of the Constant Magnetic Field of the Earth

Gaussian theory was not applicable to the causes of the terrestrial magnetism, but made possible subsequently the solution of certain problems, relevant to its nature. One of such problems was the problem on the sites of the sources, which create the terrestrial magnetic field. Gauss' theory made possible the representation of the earth's magnetic field in the form of two fields: the field, the sources of which are located inside the earth; and the field originating from the sources outside the earth. It turned out that the field of internal origin constitutes 94%, and that of the external

origin amounts to 6%. The reality of the external sources remains still to be proved. Lately, the opinion becomes more and more popular that, with a more exact knowledge of the earth's magnetic field, the computations in conformity with the Gaussian theory would lead to the zero value for the externally caused field.

A number of hypotheses were formulated during the latest decades. With the aid of these hypotheses, the attempts were made to explain the causes of the earth's magnetism, but up to now there is not a single, generally accepted hypothesis, which could satisfactorily explain the constant terrestrial magnetism.

A detailed exposition of the hypotheses is outside the scope of this lecture and, therefore, we will explain in the following only the main points of them.

All the contemporary theories on the terrestrial magnetism can be subdivided into two main groups: the theories which explain the main part of the earth's magnetic field by means of electric currents, and the theories based on the assumption that almost the whole magnetic field of the earth may originate in the earth's crust.

It is well known that the electrical current is always accompanied by magnetic field. The magnitude and the trend of this field can be computed proceeding from certain laws of physics.

The theories of the first group assume that the main part of the earth's magnetic field originates from the electric currents which circulate at great depths in the liquid core of the earth. The argument of these theories is that, with the existence of corresponding mechanical motions of a substance which composes the liquid core of the earth, the magnetic field in the core, negligible at the beginning, may increase up to the magnitudes which correspond with the actually-observable field. Thus, these theories are based on a series of hypotheses on the existence of initial magnetic field and motions in the core of the earth, i.e., on the theories, which are not substantiated as yet.

The theories of the second group are based on the assumptions that the earth's crust has in its different sections a variable quantity of magnetic rocks and, therefore, can serve on the whole as a source which creates the principal part of the earth's magnetic field with its characteristics. These theories, likewise, make use of a series of assumptions which so far were not substantiated by experimentation and, therefore, have to be regarded as hypotheses.

The Variable Magnetic Field of the Earth

Components of the Variable Magnetic Field of the Earth.

The earth's magnetic field is a sum of two fields: constant in terms of time, and variable. The field, variable in time, superimposing

the constant field, causes the changes in the general magnetic field of the earth. Although the magnitude of the variable magnetic field is very small and amounts throughout the most part of the time only to 0.1-0.2% of the value of a constant field, the studies of the variable field are very important in view of the fact that the variable field is associated with a number of heliophysical and geophysical phenomena, such as the corpuscular and wave-radiation of the sun, the propagation of radio waves, and the auroras. Further studies of these phenomena and their interrelationships will probably be helpful in finding out the causes of the terrestrial magnetism.

It was found out by studying the magnetograms that the variations of the magnetic field (or the magnetic elements) are sometimes smooth, and sometimes of a disorderly nature. The variations in the first instance are described as undisturbed variations, whereas in the second instance they are known as perturbed variations. The undisturbed variations are strictly periodical. They include: solar-diurnal variations with the diurnal periods, associated with the diurnal rotation of the earth; lunar-diurnal variations, the period length of which is equal to the lunar period of revolution ($24^h 50^m 28^s$ mean solar time), associated with the diurnal rotation of the earth with regard to the moon; annual variations with a period equal to one year, caused by the revolution of the earth with regard to the sun. Among the perturbed variations we can likewise single out certain periodical variations: perturbed diurnal variations with a period, equal to the solar 24-hour periods; and the magnetic pulsations, the period of which lasts for several minutes or seconds.

The lunar-diurnal variations are very small and are usually not taken into consideration in the virtual magnetic surveys. The annual variations are likewise small and, therefore, we do not intend to discuss these two types of variations.

Among the irregular types of perturbed variations we will discuss in greater detail only the magnetic storms.

Magnetic Activity

Magnetically calm days are the days, during which the magnetic elements undergo the smooth and regular variations. Magnetically perturbed days are the days when the magnetic elements are perturbed to a lesser or greater degree. The disturbance degree of magnetic field for the time interval in question is called the magnetic activity.

There are several methods by which the magnetic activity can be determined. The simplest among them result in an estimate of the sinuosity of lines on magnetograms. By using this method, the magnetic activity is characterized by arbitrary numbers 0, 1, 2, which are called the geomagnetic characteristics. If the diurnal changes of the curves on magnetograms are smooth within the boundaries which

connected to the diurnal variations, then the magnetic activity for these diurnal periods is regarded as equal to zero. In the case of sharp variations, the magnetic activity is characterized with the number 2.

The analysis of the variations has revealed that the magnetic activity is closely associated with the solar activity. One of the manifestations of this solar activity is the spot-forming activity of the sun. The number and the area of the spots on the sun's surface change continuously, and at times the spots disappear completely. The continuous observations have revealed that these variations are cyclic: the maximums and minimums of the spots recur approximately at 11 year intervals.

The solar spots are places of enormous turbulences, appearing at times on the sun's surface. As we know, the sun is a glowing gaseous sphere, consisting mostly of hydrogen, helium, and vaporized metals. The temperature of its luminous surface or photosphere is 6000°. The temperature in the interior of the sun reaches one million degrees. Under so high temperature the atoms disintegrate into their component parts. The atomic energy set free in the interior of the sun as a result of disintegration is the source of its radiation. The turbulences of enormous dimensions, in which the rapidly-expanding gasses cool down, appear occasionally near the sun's surface. Consequently, the places of turbulence on the luminous photosphere appear to us as dark spots.

Out of the miscellaneous wave radiation of the sun, the ultra-violet radiation, under the influence of which the ionization of gasses takes place, is the most interesting with respect to the knowledge of the nature of variations. Owing to the ionization, in the upper layers of the earth's atmosphere the layers are formed with a relatively great electrical conductivity. Electrical currents which cause certain types of magnetic variations may appear in these layers.

Besides the wave radiation, the sun emits into the surrounding space streams of corpuscles or particles, which carry the charges loaded with the positive and negative electricity. The streams of corpuscles, as a result of the reciprocal action with the constant magnetic field of the earth, create on it the magnetic activity and, in particular, induce the magnetic storms.

The solar activity is usually measured by a characteristic, based on the counting of the spots f , visible on the sun, as well as on the counted number of the groups of spots g . This characteristic, or measure of solar activity is given the name of W (Wolf sunspot) number, and is computed by means of expression

$$W=f+10g$$

The relation between the magnetic and solar activity becomes clearly evident when we compare the corresponding data for many years.

Fig. 10 shows the graphs of solar and magnetic activity for the period from 1830 to 1930. The graphs show that during the years of the maximum of solar spots, the magnetic activity likewise reaches its maximum and has the 11-year cycle, which coincides with the cycle of solar activity. It is likewise established that the magnetic activity recurs in 27 days, this being connected with the sun's rotation period around its axis. This recurrence is explainable by the fact that some solar spots, floccules, and the corpuscular streams associated with them, remain in existence for long time, throughout the period of several revolutions of the sun.

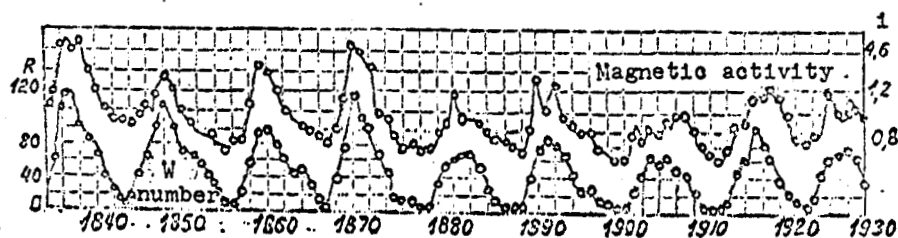


Figure 10. Solar and Magnetic Activity for the Period from 1830 to 1930 (According to J. Bartels)

R - number of solar spots
i - index of magnetic activity